



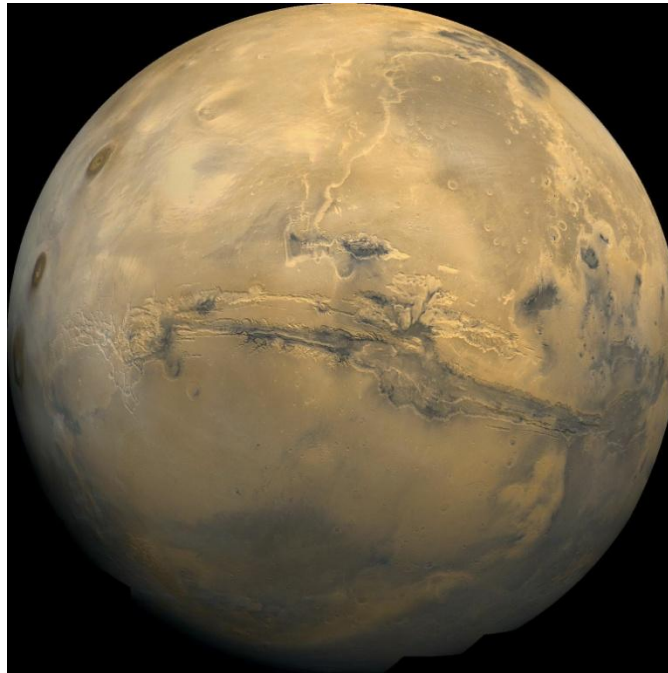
Modeling Martian Dust Using Mars-GRAM

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What is Mars-GRAM?



(Image Courtesy of: NASA/JPL/USGS)

Mars Global Reference Atmospheric Model (Mars-GRAM)



- Engineering-level atmospheric model widely used for diverse mission applications
- Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL)¹.
- From the surface to 80 km altitude, Mars-GRAM is based on NASA Ames Mars General Circulation Model (MGCM). Mars-GRAM and MGCM use surface topography from Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA), with altitudes referenced to the MOLA areoid, or constant potential surface.
- Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include:
 - TES Mapping Years 1 and 2, with Mars-GRAM data coming from MGCM model results driven by observed TES dust optical depth
 - TES Mapping Year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from MGCM model results driven by selected values of globally-uniform dust optical depth.
- Mars-GRAM 2005 has been validated² against Radio Science data, and both nadir and limb data from the Thermal Emission Spectrometer (TES)³.

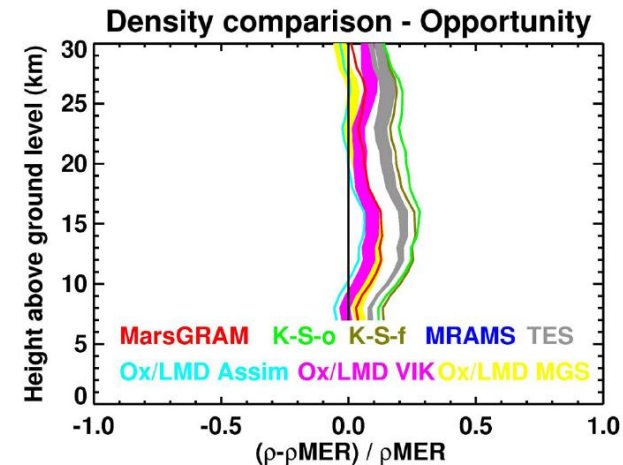
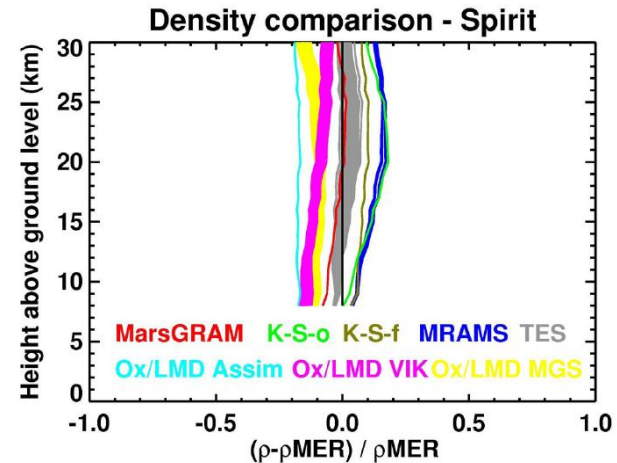


Features of Mars-GRAM 2005

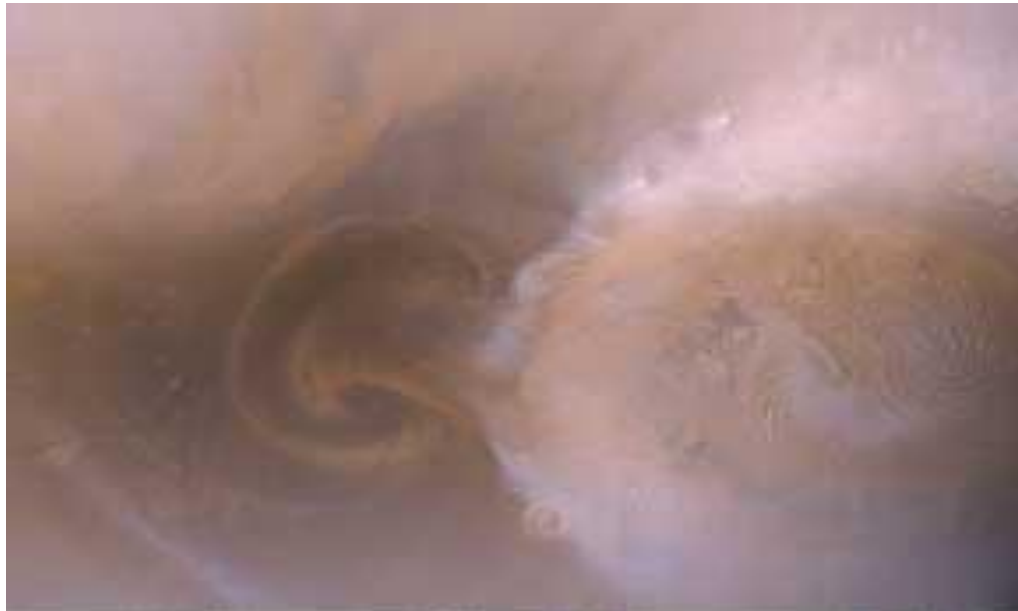
- Option to use input data sets from MGCM model runs that were designed to closely simulate conditions observed during the first two years of TES observations at Mars
 - TES Year 1 = April 1999 through January 2001
 - TES Year 2 = February 2001 through December 2002
- Option to read and use any auxiliary profile of temperature and density versus altitude. In exercising the auxiliary profile Mars-GRAM option, the values from the auxiliary profile replace data from the original MGCM databases
 - Examples of auxiliary profiles:
 - Data from TES (nadir or limb) observations
 - Mars mesoscale model output at a particular location and time
- Three Mars-GRAM parameters allow standard deviations of Mars-GRAM perturbations to be adjusted
 - rpscale can be used to scale density perturbations up or down
 - rwscale can be used to scale wind perturbations
 - wlscale can be used to adjust wavelengths (spectral range) of the perturbations

Comparison with MER EDL models

- Paul Withers at Boston University compared the MER EDL data with various models including Mars-GRAM
- Mars-GRAM averages within 5% of the MER values
- For surface-pressure corrected results, Mars-GRAM is one of two models that averages a ratio of 1.0 to the MER data, the other is MGCM (TES dust)



How Does Mars-GRAM Model Dust For Mapping Year 0?



(Image Courtesy of: NASA/JPL)

Quantitative Dust Concentration Model (For Mapping Year 0)



- Background (nondust storm) dust optical depth (tau) is specified by input parameter Dusttau
 - Dusttau = Optical depth of background dust level
 - No time-developing dust storm, just uniformly mixed dust
 - Values of 0.3 to 3.0 (with extrapolation to tau=0.1)
 - If Dusttau = 0, a prescribed Viking-like seasonal variation of dust optical depth is used, in which case variation of tau with Ls (in degrees) is specified by:

$$\tau = 0.65 - 0.35 \sin(\pi Ls / 180)$$

Global or Local-Scale Dust Storms (For Mapping Year 0)



- A model for global or local-scale dust storms⁴ is retained
- INTENS = dust storm intensity, peak dust optical depth of the storm
 - Allowable values ranging from 0.0 (no dust storm) to 3.0 (maximum intensity dust storm)
 - Dust storm intensity is added to background dust optical depth to give total dust optical depth
- Calculates all necessary interpolations on dust optical depth as it varies with time, Ls, and space for local storms
- DUSTLAT and DUSTLON gives the location of the dust storm
- ALSDUR allows users to control the duration of simulated dust storms
- RADMAX is the maximum radius (km) a dust storm can attain
 - Developing according to the parameterized space and time profile of build-up and decay in the program
 - If a value of 0 or more than 10000 km is used, the storm is taken to be of global dimensions (uniformly covering the planet), but still assumed to build up and decay in intensity according to the same temporal profile

Dust Concentration Calculations (For Mapping Year 0)



- Mars-GRAM computes several dust concentration parameters from dust optical depth
- Methods used by Haberle, et al. in MGCM are employed^{5,6}
- Areal dust density, m_d , total column mass of dust per unit ground surface area, is $0.005 \cdot \tau$
- Dust mixing ratio at the surface, q_0 , is computed by:
$$q_0 = m_d g / (0.994 \exp^{-\nu} p_{sfc})$$
- Dust mixing ratio at height z is determined by:
$$q(z) = q_0 \exp\{ \nu [1 - p(z)/p_{sfc}] \}$$
- Dust mass density is the product of dust mixing ratio and atmospheric density
- From dust mixing ratio, Mars-GRAM also computes dust number density
- Users can input values of dust particle diameter, $Dustdiam$, and dust particle density, $Dustdens$
- Consistent with MGCM⁷, Mars-GRAM assumes default particle diameter, $5 \mu m$, and default particle density, 3000 kg/m^3

Increasing the Accuracy of Mars-GRAM Sensitivity Studies at Large Optical Depths



(Image Courtesy of: NASA/JPL)



Background

- It has been discovered during the Mars Science Laboratory (MSL) site selection process that the Mars Global Reference Atmospheric Model (Mars-GRAM) when used for sensitivity studies for TES MapYear=0 and large optical depth values such as $\tau=3$ is less than realistic
- MGCM results that were used for Mars-GRAM with MapYear=0 were from a MGCM run with a fixed value of $\tau=3$ for the entire year at all locations
- Unrealistic energy absorption by uniform atmospheric dust leads to an unrealistic thermal energy balance on the polar caps
- Outcome is an inaccurate cycle of condensation/sublimation of the polar caps and, as a consequence, an inaccurate cycle of total atmospheric mass and global-average surface pressure
- Under an assumption of unchanged temperature profile and hydrostatic equilibrium, a given percentage change in surface pressure would produce a corresponding percentage change in density at all altitudes
- Consequently, the final result of a change in surface pressure is an imprecise atmospheric density at all altitudes

Comparison Study between Mars-GRAM and MGS data



- Comparison study between Mars atmospheric density estimates from Mars-GRAM and measurements by Mars Global Surveyor (MGS) has been undertaken for locations of varying latitudes, Ls, and LTST on Mars for both TES MapYear 1 and 2
 - TES MapYear 1
 - April 1999 through January 2001
 - Normal conditions
 - TES MapYear 2
 - February 2001 through December 2002
 - Global dust storm
- As Figures 1 and 2 show, the density ratios never varied by more than 0.04 from 1 and were always within 0.02 of each other
- Results demonstrate that the observational profiles are consistent with each other and validate the TES limb data

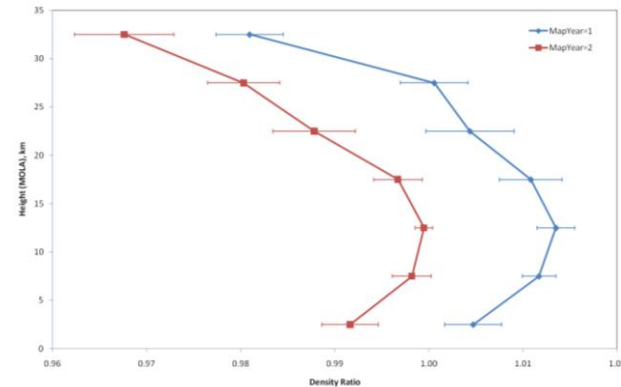


Figure 1. Atmospheric density comparison of ratios and standard deviations for TES Limb/Radio Science

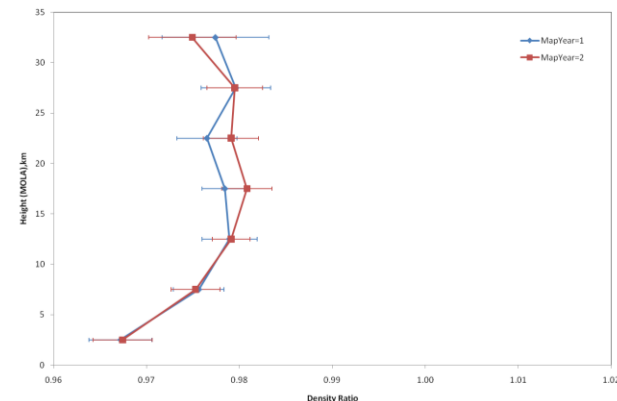


Figure 2. Atmospheric density comparison of ratios and standard deviations for TES Nadir/Radio Science

Solving the Sensitivity Study Discrepancy for Large Optical Depths



- In determining a possible solution to the discrepancy shown in the sensitivity study results for TES MapYear=0 and large optical depths, the TES Limb profiles were chosen for comparison because they extend to approximately 50 km
 - TES Radio Science and TES Nadir data extend only to approximately 35 km
 - Allows the Mars-GRAM and TES Limb profiles to be compared in the upper atmosphere
- This approach to solving this problem was derived by doing comparisons between Mars-GRAM MapYear = 0 and MapYear = 2 output
 - MapYear = 2 contains a large global dust storm, and so has a large number of $\tau = 3$ values
 - Separately, it was verified that Mars-GRAM MapYear = 2 output agreed fairly well with TES limb observations



Preliminary Fix

- Preliminary fix has been made to Mars-GRAM by adding a density factor value that was determined for $\tau=0.3$, 1 and 3
- Factor adjusts the input values of MGCM MapYear 0 pressure and density to achieve a better match of Mars-GRAM MapYear 0 with MapYears 1 and 2 MGCM output at comparable dust loading
 - Factor multiplies the $\tau = 3$ densities and pressures by about 1.2
 - Leaves the $\tau = 0.3$ and 1.0 densities and pressures almost unchanged (multipliers near 1.0)
 - Factors automatically take care of intermediate τ values between 1.0 and 3.0
- These updates can be found in Mars-GRAM 2005 Release 1.3



Current Work

- Currently, these density factors are fixed values for all latitudes and Ls
- Presently, work is being done to derive better multipliers by including possible variation with latitude and/or Ls by comparison of MapYear=0 output directly against TES limb data
- Preliminary results for $\tau=3$ have shown some latitude dependence
 - $\tau = 3$ values occurred in the limb data only near $L_s=210$
 - No L_s dependence could be determined for the high density cases
- Significantly more cases for $\tau=1$ and $\tau=0.3$ will provide more information into the latitude and L_s variations

Current Results

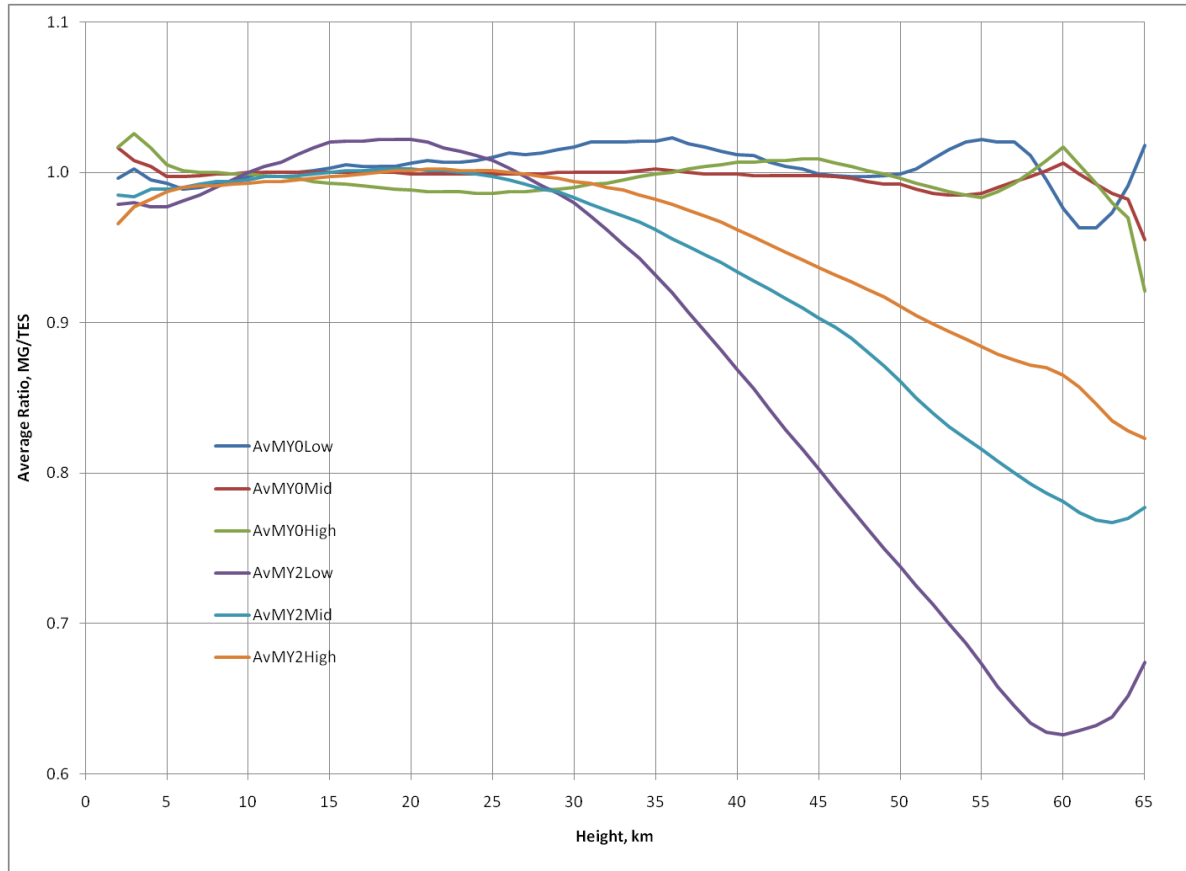


Figure 3. Profiles from Mars-GRAM using Mapping Year 2, compared with modified Mars-GRAM output using revised MGCM data for Mapping Year 0. Density ratios are Mars-GRAM (MG) relative to observed TES Limb value.

- Dust cases are:
 - Low: $\tau < 0.5$
 - Medium: $0.5 < \tau < 1.5$
 - High: $\tau > 1.5$
- Averages over all L_s values which have high dust ($L_s = 180 - 270$)

Current Results Continued

Density Map Year=2(0) Ls=All Dust=High

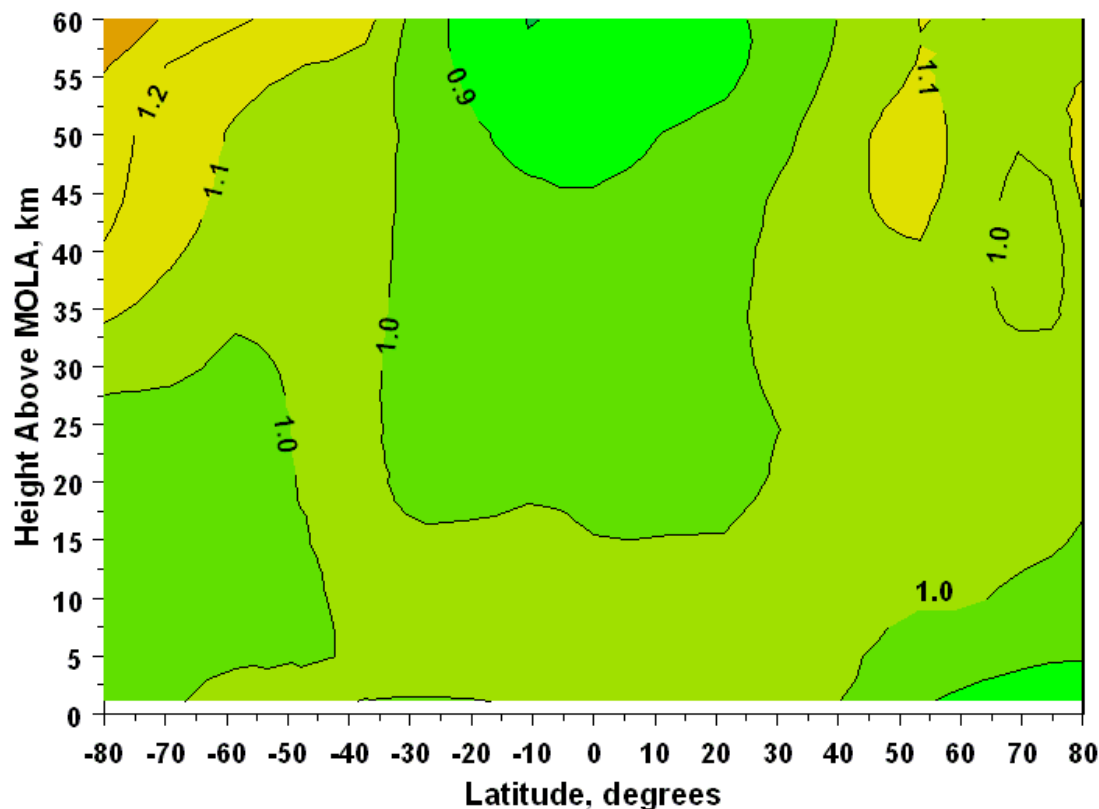


Figure 4. Lat-Height contours of ratio of MG/TES(limb) for high dust case ($\tau > 1.5$). These values are averages over all Ls values which have high dust (Ls = 180 - 270).



References

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Backup Slides

Mars-GRAM Climate Factors and Height Adjustment



- Mars-GRAM density output can be adjusted by direct height offset of MTGCM data
 - Input parameter zoffset
 - Height offset shifts such a height-vs-density curve up (or down) as it increases (or decreases) height at which a given density applies
 - Height offset adjustment affects density above 80 km
- Height offset is controlled by the use of the input parameter, ibougher
 - 0 for no Ls-dependent (Bougher) height offset term
 - 1 means add Ls-dependent (Bougher) term to constant term (zoffset):
 - Based on comparisons of MTGCM with density observed during Mars Global Surveyor (MGS) aerobraking⁸:

$$\text{Height Offset (km)} = \Delta z_0 - 2.5 \sin(\pi L_s / 180)$$

- 2 means use global mean height offset from data file hgtoffst.dat
 - 3 means use daily average height offset at local position
 - 4 means use height offset at current time and local position
 - Value of zoffset is ignored if ibougher = 2, 3, or 4
- Additional height offset of MTGCM data is applied during simulated dust storms
 - Based on comparisons between Mars-GRAM and density observed by the accelerometer⁹ on Mars Global Surveyor during the regional Noachis dust storm
 - Additional offset amount is seven times dust storm orbital depth